

EXHIBIT B



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[11] E

Patent Number: Re. 36,791**Heller**[45] **Reissued Date of Patent: Jul. 25, 2000**[54] **LOCATION SYSTEM ADAPTED FOR USE IN MULTIPATH ENVIRONMENTS**[75] Inventor: **Alan C. Heller**, San Antonio, Tex.[73] Assignee: **Precision Tracking FM, Inc.**, Dallas, Tex.[21] Appl. No.: **08/252,842**[22] Filed: **Jun. 2, 1994****Related U.S. Patent Documents**

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[56]

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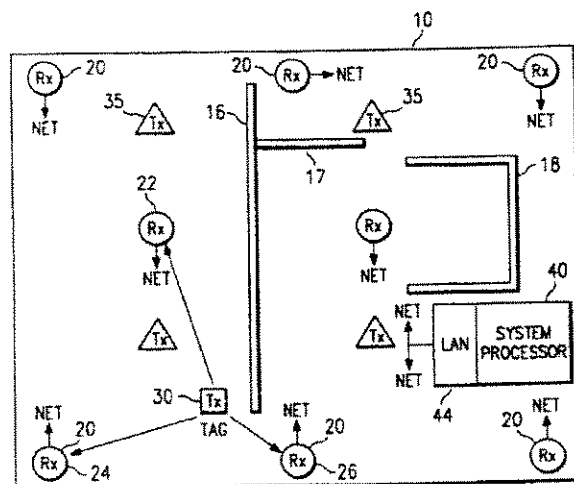
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[57]

ABSTRACT

A radiolocation system for multipath environments, such as for tracking objects in a semiconductor fabrication facility (FIGS. 1a-1b), includes an array of receivers (20) distributed within the tracking area, coupled to a system processor (40) over a LAN. A TAG transmitter (30) located with each object transmits, at selected intervals, spread spectrum TAG transmissions including at least a unique TAG ID. In a high resolution embodiment, object location is accomplished by time-of-arrival (TOA) differentiation, with each receiver (FIG. 2b) including a TOA trigger circuit (64) for triggering on arrival of a TAG transmission, and a time base latching circuit (65) for latching the TOA count from an 800 MHz time base counter. In a low resolution embodiment, each receiver of the array is assigned a specific location-area, and receives TAG transmissions almost exclusively from TAGs located in that area, thereby eliminating the need for any time-of-arrival circuitry.

75 Claims, 5 Drawing Sheets

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What is claimed is:

1. A location system for locating objects within a tracking environment using time-of-arrival differentiation for electromagnetic transmissions received at multiple receivers, comprising:

for each object, a TAG transmitter for transmitting, at selected intervals, TAG transmissions that include a unique TAG ID;

an array of receivers distributed within the tracking environment such that a TAG transmission is received by at least three receivers;

each receiver including a time-of-arrival circuit and a data communications controller;

the time-of-arrival circuit is responsive to the arrival of a TAG transmission for providing a TOA count corresponding to the time-of-arrival of the most direct path for such TAG transmission, with the TOA count being synchronized to a system synchronization clock provided to each receiver;

the data communications controller is responsive to the receipt of a TAG transmission for providing a corresponding TOA-detection packet that includes the associated TAG ID and TOA count; and

a location processor for receiving the TOA detection packets, and for determining the location of each TAG, and its associated object, from at least three corresponding TOA-detection packets received from different receivers.

2. The location system of claim 1, wherein spread spectrum communications is used for TAG transmissions.

3. The location system of claim 2, wherein the spread spectrum communications are in the frequency range of 900 Mhz.

4. The location system of claim 2, wherein the duration of a TAG transmission is around 600 microseconds.

5. The location system of claim 1, wherein each TAG transmission includes selected status information.

6. The location system of claim 5, wherein the selected status information is generated without operator intervention.

7. The location system of claim 1, wherein the TAG transmitter includes a motion detection circuit for detecting motion of the object, and for enabling the TAG transmitter to transmit TAG transmissions while the object is in motion.

8. The location system of claim 7, wherein TAG transmissions are transmitted only while the object is in motion and for a relatively short predetermined period of time after motion has ceased.

9. The location system of claim 8, wherein each TAG transmission includes an appropriate motion status indication.

10. The location system of claim 9, wherein each TAG transmission includes the appropriate one of at least three motion status indications: Motion Initiated, Motion Continuing, Motion Stopped.

11. The location system of claim 1, wherein the TAG transmitter includes a periodicity control circuit for causing the TAG transmitter to transmit TAG transmissions at selected intervals each time the object is being moved.

12. The location system of claim 11, wherein TAG transmissions are transmitted at relatively short intervals while the object is in motion, and at relatively long intervals while the object is stationary.

13. The location system of claim 1, wherein the time-of-arrival circuit provides an adjustable level of noise sensitivity for differentiating TAG transmissions from noise.

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14. The location system of claim 13, wherein noise sensitivity is determined by a selected signal level threshold and a selected signal duration threshold.

15. The location system of claim 1, wherein the time-of-arrival circuit comprises:

a TOA trigger circuit for providing a TOA-DETECT trigger immediately upon arrival of a direct-path TAG transmission; and

a time base latching circuit responsive to the TOA-DETECT trigger for latching the associated TOA count of the synchronized time base.

16. The location system of claim 15, wherein the TOA trigger circuit provides the TOA-DETECT trigger when a the signal level of a received signal exceeds a signal-level threshold, thereby indicating that the received signal is a TAG transmission.

17. The location system of claim 16, wherein the TOA trigger circuit includes a comparator for providing a TOA-DETECT trigger when the signal level of a received signal exceeds a comparator reference level.

18. The location system of claim 17, wherein the signal-level comparator reference level is adjustable.

19. The location system of claim 15, wherein the time base latching circuit indicates when the duration of the received signal exceeds a signal-duration threshold, thereby designating the received signal as a TAG transmission.

20. The location system of claim 19, wherein:

the TOA-DETECT trigger remains asserted during receipt of a TAG transmission; and

the time base latching circuit provides the signal-duration indication when the duration of the TOA-DETECT trigger exceeds a selected MAX NOISE LENGTH count.

21. The location system of claim 15, wherein the time base latching circuit includes a time base counter that counts at a rate of around 800 MHz and is derived from the system synchronization signal.

22. The location system of claim 1, wherein the receivers are coupled to the location processor by a local area network, with each receiver including a LAN interface, such that the TOA detection packets are communicated to the location processor over the LAN.

23. The location system of claim 22, wherein the system synchronization clock signal is communicated to each receiver over the LAN.

24. The location system of claim further comprising:

at least one calibration transmitter, positioned at a known location, for transmitting calibration transmissions receivable by each of the receivers;

each receiver being responsive to a calibration transmission for providing a corresponding calibration TOA detection packet, including the associated time-of-arrival TOA count, to the location processor; and

the location processor determines calibration coefficients from the calibration TOA detection packets and the known locations of the receivers, and uses those coefficients to calibrate location computations from TOA-detection packets associated with TAG transmissions.

25. A location system for locating objects within a tracking environment using area-detection by receivers that receive electromagnetic transmissions from assigned areas, comprising:

for each object, a TAG transmitter for transmitting, at selected intervals, TAG transmissions that include a unique TAG ID;

an array of receivers distributed within the tracking area, with each receiver being configured to receive TAG transmissions from an assigned area of a predetermined size;

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each receiver including a data communications controller responsive to the receipt of a TAG transmission for providing a corresponding area-detection packet that includes the received TAG ID; and

a location processor for receiving the area-detection packets, and for determining the location of each TAG, and its associated object, based on the identity of the receiver receiving the TAG transmissions for that TAG.

26. The location system of claim 25, wherein each receiver includes a directional antenna with a predetermined beamwidth, such that the receiver receives TAG transmissions originating from its assigned area.

27. The location system of claim 25, wherein:

the receivers are distributed within the tracking environment with a predetermined spacing; and

the transmitter power for each TAG transmitter and the spacing between adjacent receivers are cooperatively chosen such that a TAG transmission is almost always received by a single receiver to which the TAG is most proximate.

28. The location system of claim 25, wherein spread spectrum communications is used for the TAG transmissions.

29. The location system of claim 28, wherein the spread spectrum communications are in the frequency range of 900 Mhz.

30. The location system of claim 28, wherein the duration of a TAG transmission is around 600 microseconds.

31. The location system of claim 25, wherein the TAG transmitter includes a motion detection circuit for detecting motion of the object, and for enabling the TAG transmitter to transmit TAG transmissions while the object is in motion.

32. The location system of claim 31, wherein TAG transmissions are transmitted only while the object is in motion and for a relatively short predetermined period of time after motion has ceased.

33. The location system of claim 32, wherein each TAG transmission includes an appropriate motion status indication.

34. The location system of claim 33, wherein each TAG transmission includes the appropriate one of at least three motion status indications: Motion Initiated, Motion Continuing, Motion Stopped.

35. The location system of claim 25, wherein the TAG transmitter includes a periodicity control circuit for causing the TAG transmitter to transmit TAG transmissions at selected intervals each time the object is being moved.

36. The location system of claim 35, wherein TAG transmissions are transmitted at relatively short intervals while the object is in motion, and at relatively long intervals while the object is stationary.

37. The location system of claim 25, wherein each receiver provides an adjustable level of noise sensitivity for differentiating TAG transmissions from noise.

38. The location system of claim 37, wherein noise sensitivity is determined by a selected signal level threshold and a selected signal duration threshold.

39. The location system of claim 25, wherein the receivers are coupled to the location processor by a local area network, with each receiver including a LAN interface, such that the area detection packets are communicated to the location processor over the LAN.

40. A method for locating of objects within a tracking environment using time-of-arrival differentiation for electromagnetic transmissions received at multiple receivers, comprising the steps:

for each object, transmitting, at selected intervals, TAG transmissions that include a unique TAG ID;

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providing an array of receivers distributed within the tracking environment such that a TAG transmission is received by at least three receivers;

in response to the arrival of a TAG transmission at a receiver, providing a TOA count corresponding to the time-of-arrival of the most direct path for such TAG transmission, with the TOA count being synchronized to a system synchronization clock provided to each receiver;

in response to the receipt of a TAG transmission, providing a corresponding TOA-detection packet that includes the associated TAG ID and TOA count; and using the TOA-detection packets, determining the location of each TAG, and its associated object, from at least three corresponding TOA-detection packets received from different receivers.

41. The location method of claim 40, wherein the step of transmitting TAG transmissions further comprises detecting the motion of the object, and enabling TAG transmissions while the object is in motion.

42. The location method of claim 41, wherein each TAG transmission includes an appropriate motion status indication.

43. The location method of claim 40, wherein the step of transmitting TAG transmissions comprises the step of transmitting TAG transmissions at selected intervals each time an object is being moved.

44. The location method of claim 40, further comprising the step of adjusting receiver noise sensitivity using a signal level threshold and a signal duration threshold to differentiate TAG transmissions from noise.

45. The location method of claim 40, wherein the step of providing the TOA count comprises the steps:

providing a TOA-DETECT trigger immediately upon arrival of a direct-path TAG transmission; and

in response to the TOA-DETECT trigger, latching the associated TOA count of a time base counter derived from the system synchronism clock.

46. The location method of claim 40, wherein the receivers are coupled to the location processor by a local area network, with each receiver including a LAN interface, such that the TOA detection packets are communicated to the location processor over the LAN.

47. The location method of claim 40, further comprising the steps:

transmitting calibration transmissions from at least one known location receivable by each of the receivers;

in response to the receipt of a calibration transmission at a receiver, providing a corresponding calibration TOA detection packet, including the associated time-of-arrival TOA count; and

determining calibration coefficients from the calibration TOA detection packets and the known locations of the receivers, and using those coefficients to calibrate location computations from TOA-detection packets associated with TAG transmissions.

48. A method of locating objects within a tracking environment using area-detection by receivers that receive electromagnetic transmissions from assigned areas, comprising:

for each object, providing a TAG transmitter for transmitting, at selected intervals, TAG transmissions that include a unique TAG ID;

providing an array of receivers distributed within the tracking area, with each receiver being configured to receive TAG transmissions from an assigned area of a predetermined size;

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each receiver being responsive to the receipt of a TAG transmission for providing a corresponding area-detection packet that includes the received TAG ID; and

determining the location of each TAG, and its associated object, based on the identity of the receiver receiving the TAG transmissions for that TAG as represented by the area-detection packet provided by such receiver that received the TAG transmissions.

49. The method of claim 48, wherein each receiver includes a directional antenna with a predetermined beamwidth, such that the receiver receives TAG transmissions originating from its assigned area.

50. The method of claim 48, wherein:

the receivers are distributed within the tracking environment with a predetermined spacing; and
the transmitter power for each TAG transmitter and the spacing between adjacent receivers are cooperatively chosen such that a TAG transmission is almost always received by a single receiver to which the TAG is most proximate.

51. The location method of claim 48, wherein the set of transmitting TAG transmissions further comprises detecting the motion of the object, and enabling TAG transmissions while the object is in motion.

52. The location method of claim 51, wherein each TAG transmission includes an appropriate motion status indication.

53. The location method of claim 48, wherein the step of transmitting TAG transmissions comprises the step of transmitting TAG transmissions at selected intervals each time an object is being moved.

54. The location method of claim 48, wherein the receivers are coupled to the location processor by a local area network, with each receiver including a LAN interface, such that the TOA detection packets are communicated to the location processor over the LAN.

55. A transmitter including:

transmitter circuitry for transmitting information; and
a motion detection circuit for detecting motion and lack of motion of the transmitter, said motion detection circuit enabling the transmit circuitry to transmit information at first selected intervals when the transmitter is in motion and enabling the transmit circuitry to transmit information periodically at second selected intervals in response to detecting lack of motion,
wherein said second selected intervals are at a low duty cycle relative to said first selected intervals.

56. The transmitter of claim 55, wherein the information transmitted by the transmitter circuitry includes an appropriate motion status indication.

57. The transmitter of claim 56, wherein the motion status indication indicates one of at least three modes: Motion Initiated, Motion Continuing, Motion Stopped.

58. A transmitter including:

transmitter circuitry for transmitting information; and
a periodicity control circuit for causing the transmitter circuitry to transmit information at selected intervals in response to the transmitter being moved,
wherein the periodicity control circuit causes the transmitter circuitry to transmit at relatively short intervals while the transmitter is in motion, and at relatively long intervals while the transmitter is stationary.

59. A location system for locating objects within a tracking environment using area-detection by receivers that receive transmissions from assigned areas, comprising:

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for each object, a TAG transmitter for transmitting, at selected intervals, TAG transmissions that include a unique TAG ID, each said TAG transmitter further including a motion detection circuit for detecting motion of the object, and for enabling the TAG transmitter to transmit TAG transmissions while the object is in motion;

an array of receivers distributed within the tracking area, with each receiver being configured to receive TAG transmissions from an assigned area of a predetermined size;

each receiver including a data communications controller responsive to the receipt of a TAG transmission for providing a corresponding area-detection packet that includes the received TAG ID; and

a location processor for receiving the area-detection packets, and for determining the location of each TAG, and its associated object, based on the identity of the receiver receiving the TAG transmissions for that TAG.

60. The location system of claim 59, wherein TAG transmissions are transmitted only while the object is in motion and for a relatively short predetermined period of time after motion has ceased.

61. The location system of claim 60, wherein each TAG transmission includes an appropriate motion status indication.

62. The location system of claim 61, wherein each TAG transmission includes the appropriate one of at least three motion status indications: Motion Initiated, Motion Continuing, Motion Stopped.

63. The location system of claim 59, wherein the TAG transmitter includes a periodicity control circuit for causing the TAG transmitter to transmit TAG transmissions at selected intervals each time the object is being moved.

64. The location system of claim 63, wherein TAG transmissions are transmitted at relatively short intervals while the object is in motion, and at relatively long intervals while the object is stationary.

65. A location system for locating objects within a tracking environment using area-detection by receivers that receive transmissions from assigned areas, comprising:

for each object, a TAG transmitter for transmitting, at selected intervals, TAG transmissions that include a unique TAG ID;

an array of receivers distributed within the tracking area, with each receiver being configured to receive TAG transmissions from an assigned area of a predetermined size;

each receiver including a data communications controller responsive to the receipt of a TAG transmission for providing a corresponding area-detection packet that includes the received TAG ID;

a location processor for receiving the area-detection packets, and for determining the location of each TAG, and its associated object, based on the identity of the receiver receiving the TAG transmissions for that TAG; and

wherein each receiver provides an adjustable level of noise sensitivity for differentiating TAG transmissions from noise.

66. A location system for locating objects within a tracking environment using area-detection by receivers that receive transmissions from assigned areas, comprising:

for each object, a TAG transmitter for transmitting at selected intervals, TAG transmissions that include a unique TAG ID;

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an array of receivers distributed within the tracking area, with each receiver being configured to receive TAG transmissions from an assigned area of a predetermined size;

each receiver including a data communications controller responsive to the receipt of a TAG transmission for providing a corresponding area-detection packet that includes the received TAG ID;

a location processor for receiving the area-detection packets, and for determining the location of each TAG, and its associated object, based on the identity of the receiver receiving the TAG transmissions for that TAG; and

a local area network, said array of receivers being coupled to the location processor by said local area network, with each receiver including a LAN interface, such that the area detection packets are communicated to the location processor over said LAN.

67. A method of locating objects within a tracking environment using area-detection by receivers that receive transmissions from assigned areas, comprising:

for each object, providing a TAG transmitter for transmitting, at selected intervals, TAG transmissions that include a unique TAG ID;

providing an array of receivers distributed within the tracking area, with each receiver being configured to receive TAG transmissions from an assigned area of a predetermined size;

each receiver being responsive to the receipt of a TAG transmission for providing a corresponding area-detection packet that includes the received TAG ID;

determining the location of each TAG, and its associated object, based on the identity of the receiver receiving the TAG transmissions for that TAG as represented by the area-detection packet provided by such receiver that received the TAG transmissions;

said receivers being distributed within the tracking environment with a predetermined spacing; and

the transmitter power for each TAG transmitter and the spacing between adjacent receivers being cooperatively chosen such that a TAG transmission is almost always received by a single receiver to which the TAG is most proximate.

68. A method of locating objects within a tracking environment using area-detection by receivers that receive transmissions from assigned areas, comprising:

for each object, providing a TAG transmitter for transmitting, at selected intervals, TAG transmissions that include a unique TAG ID;

providing an array of receivers distributed within the tracking area, with each receiver being configured to receive TAG transmissions from an assigned area of a predetermined size;

each receiver being responsive to the receipt of a TAG transmission for providing a corresponding area-detection packet that includes the received TAG ID;

determining the location of each TAG, and its associated object, based on the identity of the receiver receiving the TAG transmissions for that TAG as represented by the area-detection packet provided by such receiver that received the TAG transmissions; and

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wherein the set of transmitting TAG transmissions further comprises detecting the motion of the object, and enabling TAG transmissions while the object is in motion.

69. The location method of claim 68, wherein each TAG transmission includes an appropriate motion status indication.

70. A method of locating objects within a tracking environment using area-detection by receivers that receive transmissions from assigned areas, comprising:

for each object, providing a TAG transmitter for transmitting, at selected intervals, TAG transmissions that include a unique TAG ID;

providing an array of receivers distributed within the tracking area, with each receiver being configured to receive TAG transmissions from an assigned area of a predetermined size;

each receiver being responsive to the receipt of a TAG transmission for providing a corresponding area-detection packet that includes the received TAG ID;

determining the location of each TAG, and its associated object, based on the identity of the receiver receiving the TAG transmissions for that TAG as represented by the area-detection packet provided by such receiver that received the TAG transmissions; and

wherein the step of transmitting TAG transmissions comprises the step of transmitting TAG transmissions at selected intervals each time an object is being moved.

71. A method of locating objects within a tracking environment using area-detection by receivers that receive transmissions from assigned areas, comprising:

for each object, providing a TAG transmitter for transmitting, at selected intervals, TAG transmissions that include a unique TAG ID;

providing an array of receivers distributed within the tracking area, with each receiver being configured to receive TAG transmissions from an assigned area of a predetermined size;

each receiver being responsive to the receipt of a TAG transmission for providing a corresponding area-detection packet that includes the received TAG ID;

determining the location of each TAG, and its associated object, based on the identity of the receiver receiving the TAG transmissions for that TAG as represented by the area-detection packet provided by such receiver that received the TAG transmissions; and

wherein the receivers are coupled to the location processor by a local area network, with each receiver including a LAN interface, such that the TOA detection packets are communicated to the location processor over the LAN.

72. The transmitter of claim 56, wherein the motion status indication further indicates a fourth mode: No Motion.

73. The transmitter of claim 57, wherein the information transmitted by the transmitter circuitry includes an appropriate motion status indication.

74. The transmitter of claim 73, wherein the motion status indication indicates one of at least three modes: Motion Initiated, Motion Continuing, Motion Stopped.

75. The transmitter of claim 74, wherein the motion status indication further indicates a fourth mode: No Motion.

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